2017-05-02

The height of the cricothyroid membrane on computed tomography scans in trauma patients

Nutbeam, T

http://hdl.handle.net/10026.1/9570

10.1111/anae.13905
Anaesthesia
Wiley

The height of the cricothyroid membrane on computed tomography scans in trauma patients

(*Please see published copy of this article in Anaesthesia 2017; DOI: 10.1111/anae.13905; http://onlinelibrary.wiley.com/doi/10.1111/anae.13905/full*)

Nutbeam T,[1] Clarke R,[2] Luff T,[3] Enki D,[4] Gay D.[5]

1) Tim Nutbeam, timnutbeam@nhs.net
   Consultant in Emergency Medicine/ Clinical Academic, Derriford Hospital, Plymouth, UK

2) Richard Clarke, richardclarke@nhs.net
   Flt Lt, Royal Air Force, Department of Radiology, Derriford Hospital, Plymouth, UK

3) Thomas Luff, tluff@nhs.net
   Radiology Registrar, Department of Radiology, Derriford Hospital, Plymouth, UK

4) Doyo Enki, doyo.enki@plymouth.ac.uk
   Research Fellow, Plymouth University Peninsula Schools of Medicine and Dentistry, Plymouth, UK

5) David Gay, davegay@nhs.net
   Surgeon Commander, Royal Navy, Department of Radiology, Derriford Hospital, Plymouth, UK

Correspondence to:

Dr Tim Nutbeam
timnutbeam@nhs.net
Consultant in Emergency Medicine,
The Emergency Department
Derriford Hospital,
Plymouth,
PL6 8DH

Key words:

Failed intubation: treatment

Difficult airway algorithm

Summary:

Emergency cricothyrotomy is a common feature in all difficult airway algorithms. It is the final step following failed attempts to oxygenate a patient. It is rarely performed and has a significant failure rate. There is variation in the reported size of the cricothyroid membrane, especially across population groups. Procedure failure may result from attempting to pass a device with too large an external diameter through the cricothyroid membrane.

This is a single centre UK based study. An initial sample of 61 trauma CT scans were reviewed by two radiologists independently. Electronic calipers were used to measure the maximum height of the cricothyroid membrane. This sample was used to power further data collection to a precision of 0.2mm – further scans were reviewed until the required sample size of 478 patients was achieved.

The median height of the cricothyroid membrane in this group was 5.85 mm (female) and 7.65mm (male). These dimensions are much smaller than previously reported in the literature for Western patients. The external diameters of devices used to pass through the cricothyroid membrane were compared with these measurements.

The cricothyroid membrane in this population is smaller than previously reported. There is a relationship between age and cricothyroid membrane height in adult male patients. Practitioners encountering patients who may require an emergency surgical airway should be aware of this data. Rescue airway equipment of a variety of external diameters should be immediately available.

The height of the cricothyroid membrane on computed tomography scans in trauma patients

Background:

Broadly speaking there are four modes of managing the airway: face mask, supraglottic airway (SAD), tracheal tube and direct access to the trachea. 'Can't Intubate Can't Oxygenate' (CICO) scenarios are rare but frequently catastrophic: CICO accounts for over 25% of all anesthesia-related deaths[1].

When other forms of airway management fail, routes of direct access to the trachea are used. An emergency surgical airway is the last step in all difficult airway algorithms. A surgical airway involves making an incision through the cricothyroid membrane and inserting a tube[2].

Various recommendations exist as to the correct size tube to place during emergency surgical airway with commonly used devices ranging between 5.0mm (QuickTrach 2, Rusch) and 10.8mm (Shiley) in external diameter. The Difficult Airway Society recommended a 6.0mm ET tube which has an external diameter of up to 8.0mm[2].

The size of the cricothyroid membrane in the western population is reported as 7.5 – 10.5mm in female cadavers and 10.0 - 13.0 in male cadavers[3 – 5]. A study examining the south Indian population found the cricothyroid membrane to be much smaller 3.0 - 8.4mm in the female and 3.0-10.0mm for the male cadavers[6]. The same study reported that the height of the cricothyroid membrane should be used to judge appropriate tube size for emergency surgical airway use – the external diameter should be smaller than the height of the cricothyroid membrane measured in the neutral position.

Emergency cricothyrotomy often takes longer than would be expected and has a high complication and failure rate (approximately 30%)[7]. Procedure failure may result from attempting to pass a device with too large an external diameter through the cricothyroid membrane. Furthermore, placement of an oversized tube can lead to fracture of the laryngeal cartilage, complications of which include dysphonia and subglottic stenosis[3].

The authors set out to establish the size of the cricothyroid membrane in a UK trauma population.

Methods:

Patients presenting between January 2014 and June 2015 who were received at the Major Trauma Centre (MTC), Derriford, Plymouth and who received a Trauma CT scan as part of their initial imaging strategy had their images reviewed. This was a daily convenience sample, reviewing the previous days imaging.

The pan CT scans were viewed on the Insignia InSight Picture Archiving and Communication System (PACS). The pan CT scans were reformatted into a 0.625mm multi planar reformat (MPR) and viewed simultaneously in the three orthogonal planes; axial, coronal and sagittal; this is a commonly used radiological technique and allows accurate identification of the midline. The radiology trainees participating in the measurement element of this study were specifically trained in this technique under guidance from an experienced consultant radiologist. The trainee radiologists application of this technique was further refined under direct supervision to ensure a reproducible accurate measurement could be made. Alternative methods of measurement were considered but were not found to be useful in this setting. Reconstructed midline sagittal images of the neck were viewed and the maximum height of the cricothyroid membrane was measured using electronic calipers available on the PACS. Measurements were made between the most anterior, superior aspect of the cricoid cartilage and the most anterior, inferior process of the thyroid cartilage where the cricothyroid membrane attaches (Figure 1). This measurement, through not strictly the height of the cricothyroid membrane delineates the dimensions through which a tube should pass when performing a surgical airway, and as such is the clinically important measurement in this setting.

These measurements were taken independently by two radiology registrars, blinded to each other's measurements. Scans where the measurement could not be taken were excluded from analysis. Scans were excluded when they did not include the cricothyroid membrane (e.g. a trauma scan excluding the head and neck) or if movement artefact during image acquisition prevented accurate measurement. Scans were also excluded if the patients were found not to have calcification of the thyroid and cricoid cartilage – calcification of these areas was required in order to clearly delineate the tissue dimensions and allow reproducible measurement. CT scans of the young and female patients were less likely to have sufficient calcification so were more likely to be excluded from analysis.

A pilot sample of size 61 scans was used to get an initial estimate for the standard deviation of 2.2mm required for sample size calculation. Sample size of 478 was obtained by assuming 5% level of significance and 95% confidence interval with precision of 0.2mm on the measurements of the heights.

In addition to cricothyroid membrane height, data on patients' age and sex was recorded alongside the patient's intubation and cervical spine immobilisation status. Intra-class correlation (ICC) and Krippendorff's alpha were used to assess interrater agreement between the two radiologists. Normality distribution of the height data was checked using Shapiro-Wilks test. Descriptive statistics along with 95% confidence intervals were reported. Relevant results were given by sex and age category.

This study was approved as a service evaluation by Plymouth Hospitals NHS Trust and was subsequently registered with the trusts audit team (Ref: CA_2016-17-136).

Results:

A total of 745 trauma scans were assessed during the study period of which 482 were suitable for analysis.

Height measurements were made on a total of 482 scans, of which 21.8% correspond to female patients.

Table 1 displays the mean (SD) height of cricothyroid membrane for male and female, as measured by each radiologist. There was a statistically significant difference in the height between male and female ($p<.001$). The mean (SD) age for male and female were 51.0 (18.6) and 62.8 (16.9) years, respectively.

The test of interrater agreement gives an ICC of 0.89 (95% CI = (0.87, 0.91)) and Krippendorff's alpha of 0.87, showing an excellent agreement between the two radiologists. As a result, further data analysis in this paper is based on the measurements made by the first radiologist.

Age was categorised into eight groups as shown in Figures 2 and 3. There is a clear indication of a relationship between age and height of cricothyroid membrane, especially in male subjects. This prompted the investigators to formally test if the height significantly changes with age for each gender separately. It was found that the height was significantly related to the age for males as determined by one-way ANOVA ($F(7,366) = 4.80$, $p < .001$). Table 2 depicts the mean (SEM) [95% CI] height by age group for male and female. A Tukey post hoc test further revealed that the mean heights for the two lower age groups (16-25 and 26-35) were not statistically significantly different from each other, but the mean height of each of the two age groups was significantly different from the rest of the groups (except the last age group, which might be affected by the small number of subjects within the group). In addition, the mean heights of the last six age groups were not found to be significantly different from each other. As a result, the ages were regrouped into two as 16-35 and 36-93 years and the corresponding mean heights tested - as expected this was found to be highly significant, $p < .001$. The mean (SEM) [95% CI] height for the 16-35 and 36-93 years were 6.59 (.19) [6.21, 6.97] mm and 8.25 (.12) [8.00, 8.49] mm, respectively.

Such difference was not observed for females. This could be attributed to the small number of female scans in general and lack of enough scans in the lower two age groups in particular. Considering the last six age groups alone, it was found that there was no statistically significant relationship between age and height of the membrane ($F(5,96) = 0.29$, $p=0.917$). This result was similar to that of male for this age group (36-93 years). The mean (SEM) [95% CI] height for a combined age group was then 6.02 (.18) [5.67, 6.36].

The presence or absence of concurrent intubation or cervical spine immobilisation was found not to have a significant effect on CTM height.

Patient cricothyroid membrane heights were compared to the external diameter of commonly recommended surgical airway devices (Table 3).

Discussion:

This is the largest reported series detailing the height of the cricothyroid membrane.

The height of the cricothyroid membrane within this adult western trauma population is considerably smaller than that previously reported. This is the first time an age dependent relationship in size of cricothyroid membrane amongst male adult patients has been identified. This information has important implications for emergency airway management, including: training, preparation and equipment selection.

This study is the first of its kind and as such, this method of measurement of the cricothyroid membrane has not been validated. Validation would include direct comparison to dissection, visualisation and measurement in live subjects and as such will be difficult to achieve. The authors consider that these results are likely to reflect the true-to-life anatomy of the cricothyroid membrane, as this is considered to be a ubiquitous feature of CT imaging. The authors concede that the static height as per our measurements may not be a direct reflection of 'capacity' of the space in terms of the external diameter of the tube that could be inserted through it. The capacity of the cricothyroid membrane is likely to be affected by patient positioning and the pliability of the surrounding tissues.

Patient positioning and its effect on cricothyroid membrane capacity: The nature of the trauma scan means that these measurements were recorded with the head in the neutral position. Mobility at the synovial cricothyroid joint results in a greater height of the membrane if the head were to be placed in full extension. Full extension increases the height of the cricothyroid membrane by up to 20% [3,5]. Even with this extension this would still result in a cricothyroid membrane height considerably smaller than that previously reported. Due to calcification associated with the ageing process, the proportional increase in cricothyroid membrane height achieved by extension is likely to decrease with age. In addition, the limitations of management of trauma patients (e.g. on a scoop / immobilised), patient factors such as cervical kyphosis, and ENT pathologies may also prevent extension.

The pliability of the tissues surrounding the CTM may allow a larger tube to be passed. However, the cartilaginous tissues do not have a large mechanical stretch capacity. Placement of an oversized tube is known to result in fracture of the laryngeal cartilage in humans [3]. Slow dilation of the tissue may result in a larger capacity – but this is unlikely to be feasible in the setting of an emergency surgical airway. Previous cadaveric work has recommended the vertical height of the cricothyroid membrane in the neutral position to be used to determine the maximum external diameter of the emergency surgical airway device [6].

The authors conclude that it is valid to make recommendations on equipment sizes based on cricothyroid membrane measurements using CT measurement with the head in a neutral position.

The relationship between cricothyroid membrane height and age was found only within the male population. The authors hypothesise from the data collected, that this relationship may exist within the female population too - a larger number of patients would be required to demonstrate this. This relationship appears to show a gradual increase in height from the teens to the fourth decade, followed by a plateau between the fourth and sixth decade following a decrease in height with increasing age.

Further useful work based on this methodology would include: collecting longitudinal CTM height data on patients over the decades; defining the relationship between patients total height and their CTM height; externally validating these findings across a variety of population groups. The collection of additional data will support the derivation of a decision rule to predict the height of the cricothyroid membrane for a given patient – this would be clearly be useful clinically in ensuring the preparation of appropriately sized kit before attempting a surgical airway.

Ultrasound has been widely used to identify the location of the CTM in a variety of settings. It has been found to be superior to palpation alone and some authors recommend its routine use in those who's CTM is difficult to palpate [8]. The dimensions of the CTM can be seen on ultrasound in some patients – the proportion of patients in which the CTM can be accurately delineated, (as opposed to just located), the accuracy and interrater reliability of such measurements has not been reported in the literature. Until this data is known, it is difficult to recommend the routine use of ultrasound to identify the dimensions of the CTM in elective practice. In the setting of an emergency airway crisis it is recommend that if time allows, a skilled operator may use ultrasound to identify the location of the CTM – attempts to delineate the size we do not yet know to be useful and so cannot be recommended.

Considering the high failure rate of emergency surgical airway as a procedure and these study findings, the authors recommend that a selection of tube sizes for access to the cricothyroid membrane are available whenever this procedure may need to be performed. Endotracheal tube sizes of at least size 3, 4 and 5 (internal diameter) and an appropriate sized bougie should be readily available at all attempts. Information related to the likely size of the cricothyroid membrane should be included in theoretical and practical training sessions on this subject – the practitioner should not be surprised when their first choice of tube does not pass.

Acknowledgements:
No external funding and no competing interests declared.

References:

1. Cook TM, Woodall N, Frerk C, eds. *The NAP4 report: Major complications of airway management in the UK.* Royal College of Anaesthetists. London; 2011. **http://www.rcoa.ac.uk/index.asp?PageID=1089** Accessed 30 September 2016.

2. Frerk C, Mitchell VS, McNarry AF et al. Difficult Airway Society 2015 guidelines for management of unanticipated difficult intubation in adults. *British Journal of Anaesthesia* 2015; **115**: 827-848..

3. Boon JM, Abrahams PH, Meiring JH, Welch T. Cricothyroidotomy: a clinical anatomy review. *Clinical Anatomy* 2004; **17**: 478–86.

4. Dover K, Howdieshell TR, Colborn GL. The dimensions and vascular anatomy of the cricothyroid membrane: relevance to emergent surgical airway access. *Clinical Anatomy* 1996; **9**: 291–5.

5. Bennett JD, Guha SC, Sankar AB. Cricothyrotomy: the anatomical basis. *Journal of the Royal College of Surgeons Edinburgh* 1996; **41**: 57–60.

6. Prithishkumar IJ, David SS. Morphometric analysis and clinical application of the working dimensions of cricothyroid membrane in south Indian adults: With special relevance to surgical cricothyroidotomy. *Emergency Medicine Australasia* 2010; **22:** 13–20.

7. Langvad S, Hyldmo PK, Nakstad AR, Vist GE, Sandberg M. Emergency cricothyrotomy--a systematic review. *Scandinavian Journal of Trauma Resuscitation and Emergency Medicine* 2013; **21:** 43.

8. Kristensen MS, Teoh WH, Rudolph SS. Ultrasonographic identification of the cricothyroid membrane: best evidence, techniques, and clinical impact. *British Journal of Anaesthesia*. 2016; 117: i39-i48

Table 1: Measurement for height of cricothyroid membrane by Radiologist and Gender

Gender	Mean (SD) height (mm) as measured by	
	Radiologist 1	Radiologist 2
Female	6.00 (1.76)	5.92 (1.71)
Male	7.89 (2.21)	7.88 (2.22)

Table 2: Measurement for height of cricothyroid membrane by age group and gender as measured by Radiologist 1

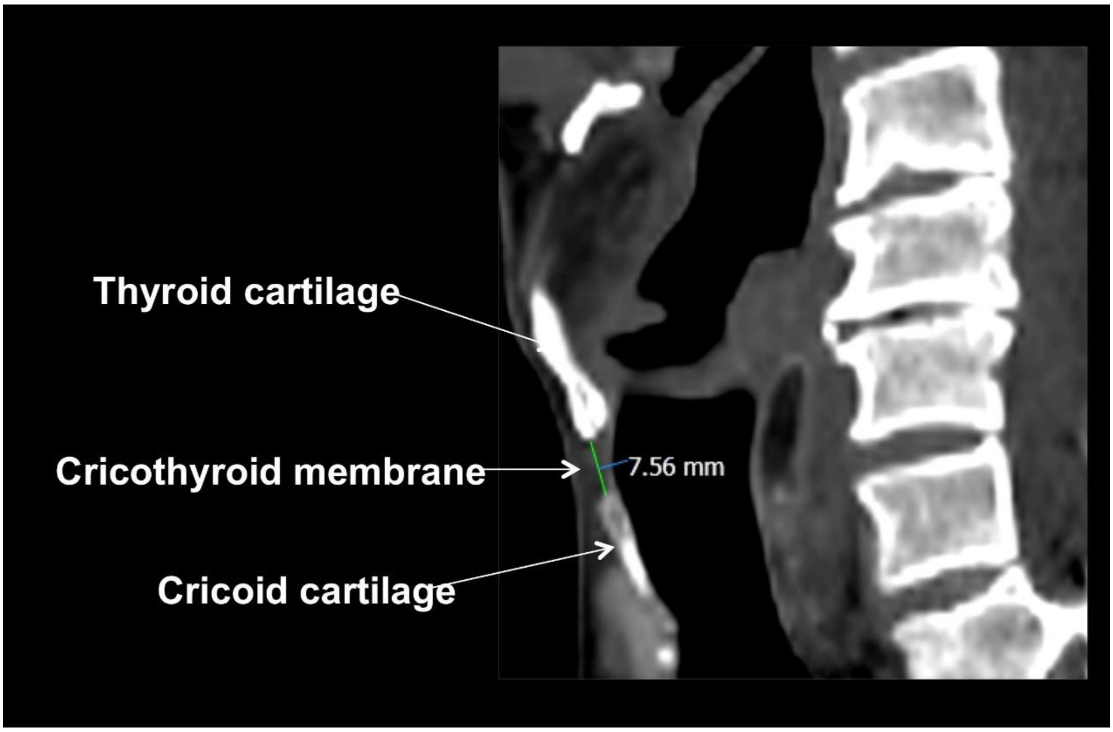
Age (years)	Male		Female	
	Number (%) of scans	Mean (SEM)* [95% CI] height (mm)	Number (%) of scans	Mean (SEM)* [95% CI] height (mm)
16-25	29 (7.7)	5.90 (.24) [5.40, 6.40]	2 (1.9)	N/A**
26-35	60 (15.9)	6.82 (.24) [6.35, 7.30]	1 (1.0)	N/A**
36-45	61 (16.2)	8.07 (.25) [7.56, 8.57]	13 (12.4)	6.12 (.64) [4.73, 7.52]
46-55	76 (20.1)	8.51 (.22) [8.06, 8.95]	24 (22.9)	6.19 (.42) [5.31, 7.06]
56-65	56 (14.9)	8.37 (.31) [7.74, 9.00]	19 (18.1)	6.12 (.35) [5.40, 6.85]
66-75	51 (13.5)	8.46 (.31) [7.84, 9.07]	15 (14.3)	5.66 (.40) [4.81, 6.51]
76-85	27 (7.2)	8.04 (.41) [7.21, 8.88]	23 (21.9)	6.08 (.34) [5.38, 6.79]
86-93	17 (4.5)	7.19 (.39) [6.36, 8.01]	8 (7.6)	5.56 (.54) [4.28, 6.84]

(*SEM = Standard Error of the Mean; **N/A = Not Available due to small number of scans)

Table 3: Comparison of common emergency surgical airway devices, their external diameter and the percentage of the population in which the cricothyroid membrane height is greater than the external diameter of the device.

Device type	**External diameter**	**% of population in which cricothyroid membrane height > external diameter of device**
6 mm ET	8.0	36.2
5 mm ET	6.7	60.5
4 mm ET	5.6	77.6
3 mm ET	4.2	93.2
Shilley	10.8	7.7
Melker	8.2	34.6
TracheoQuick	5.0	86.5

Figure 1: Midline sagittal reconstruction of the neck



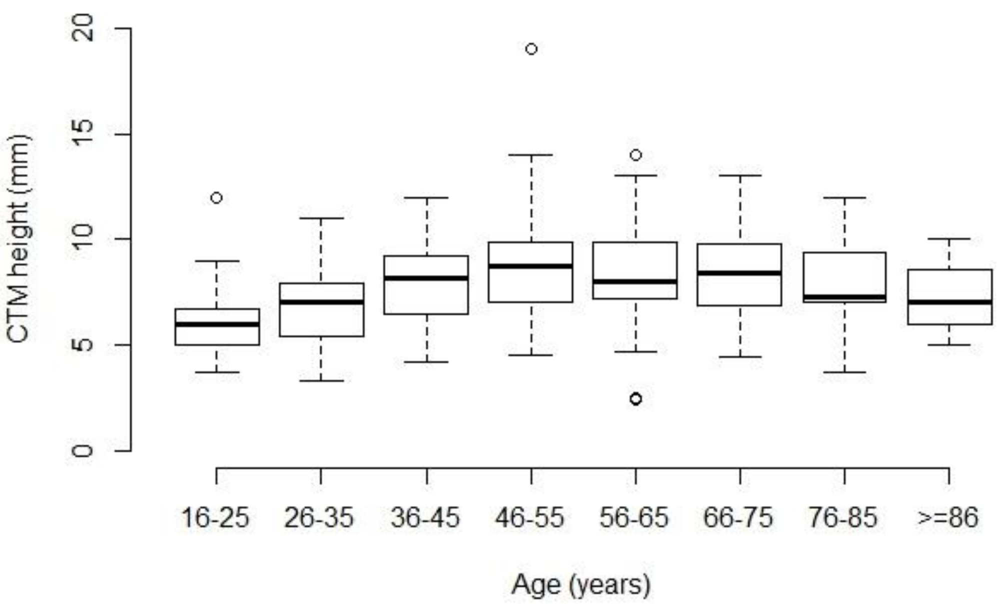


Figure 2: Height of cricothyroid membrane with age (Male). Interquartile range [IQR] (vertical size of box), median (band inside box), outlier (circle), ±1.5*IQR (whisker)

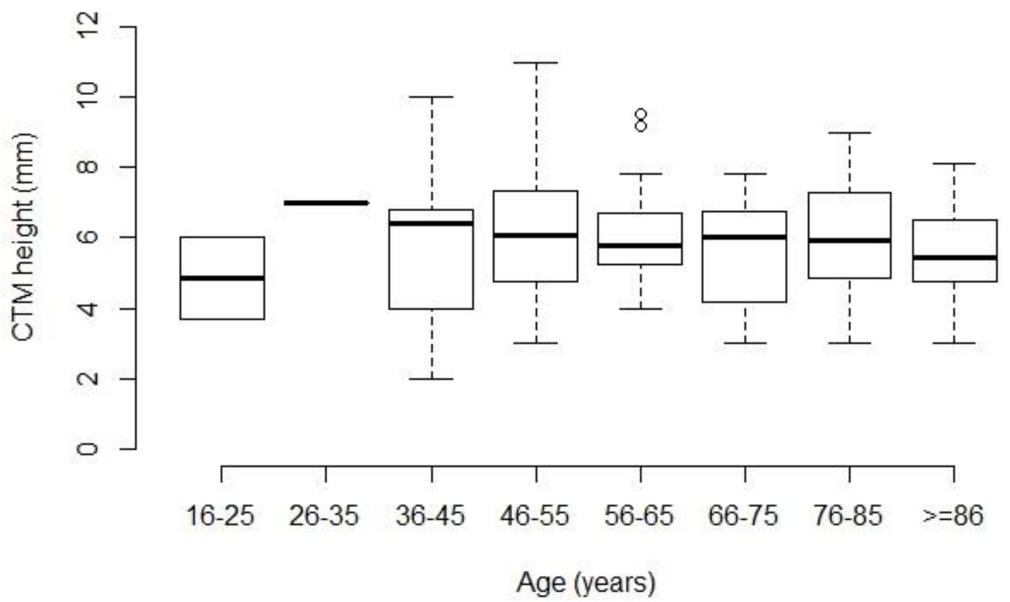


Figure 3: Height of cricothyroid membrane with age (Female). Interquartile range [IQR] (vertical size of box), median (band inside box), outlier (circle), ±1.5*IQR (whiskers)